




Solar Photovoltaic Systems



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Solar Photovoltaic Systems



Developed in Partnership with:













Department of Planning and Development



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Solar Photovoltaic Systems








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Solar Photovoltaic Systems




- What is PV?
- Where is it installed?
- Installation requirements

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What is PV?




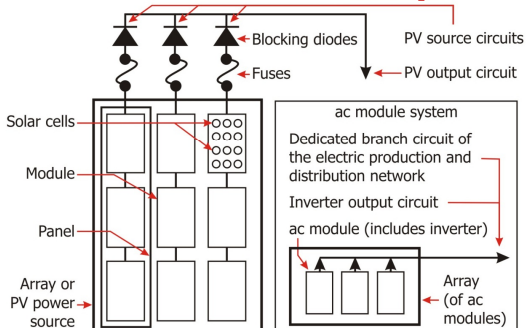
- Definition: Solar Photovoltaic System**
- The total components and subsystems that, in combination, convert solar energy into electrical energy suitable for connection to a utilization load

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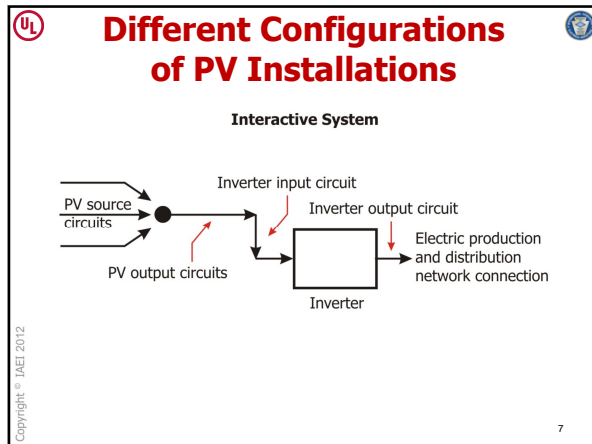
Basic Components of a Solar Photovoltaic System

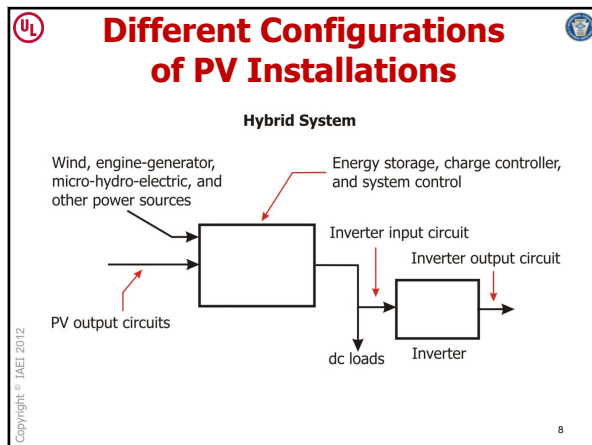


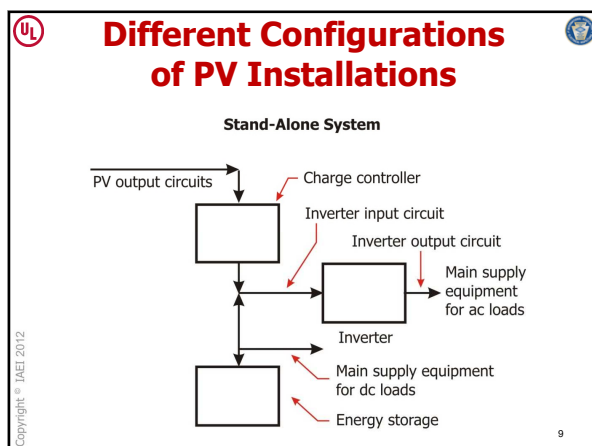


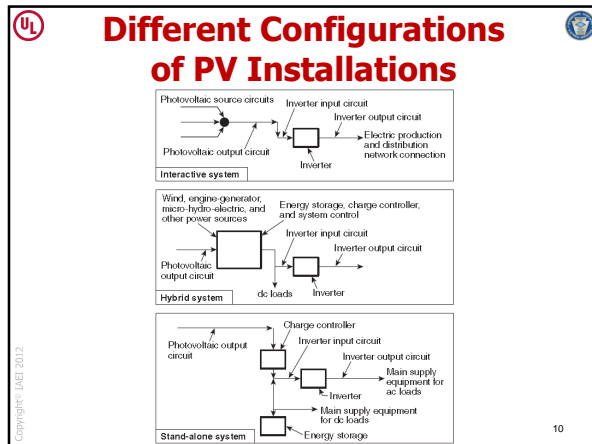
NEC Figure 690.1(A)

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UL **Where is PV Installed?**



- **NEC 690.4(A) Photovoltaic systems**
- **Photovoltaic systems** shall be permitted to supply a building or other structure in addition to any **other** electricity supply system(s)

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Commercial Rooftops





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Shade Structures







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Ground Mounted



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Windows






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Skylights



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Awnings




Photo courtesy of DOE/NREL



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Pole Top Mount





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Solar Generating Plant








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PV Installation Concerns




- Utility compatibility and interaction
- Environment
(e.g. indoor, rainproof, corrosion resistant)
- Maximum number of modules
- Fire exposure ratings
- Location on roof
- Effect on roof covering
- Wind and snow loading

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Items needed to Inspect PV?




- Permits
- Plans
- Wiring
- Attachment
- Equipment

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Plans - Electrical




- **Electrical plan should be submitted that includes the following:**
 - Locations of main service or utility disconnect
 - Total number of modules, number of modules per string and the total number of strings
 - One-line diagram of system
 - Specify grounding/bonding, conductor type and size, conduit type and size and number of conductors in each section of conduit

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Plans - Electrical (cont.)




- **Electrical plan should be submitted that includes the following:**
 - Make and model of modules, inverter(s) and/or combiner box if used
 - If batteries are to be installed include them in the diagram and show there locations and venting
 - Equipment cut sheets including inverters, modules, AC and DC disconnects and combiners

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Plans - Electrical (cont.)




- **Electrical plan should be submitted that includes the following:**
 - Labeling of equipment as required by Article 690 and Article 705
 - Site diagram showing the arrangement of modules on the roof or ground, north arrow, lot dimensions, and the distance from property lines to adjacent buildings/structures (*existing and proposed*)

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Plans - Structural




- **Structural plan identifying support information for roof mounted systems including the following:**
 - The type of roof covering and the number of roofing layers installed
 - Type of roof framing, size of members and spacing
 - Weight of modules, support locations and method of attachment

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Plans - Structural (cont.)




- **Structural plan identifying support information for roof mounted systems including the following:**
 - Framing plan and details for any work necessary to strengthen the existing roof structure
 - Any relevant calculations (*when required*)
 - Location of PV equipment on the building

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Plans - Structural (cont.)




- **Structural plan identifying support information for roof mounted systems including the following:**
 - Where an approved racking system is used...
 - provide documentation showing the manufacturer of the rack system
 - maximum allowable weight the system can support
 - attachment method to the roof or ground
 - product evaluation information or structural design for the rack system

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Plans - Code Requirements




- **Site Plan** –
NEC 80.21 (Annex H), IBC 107.2.5, IRC R106.2
- **One-Line Diagram** –
NEC 215.5
- **Attachment Details** –
NEC 110.3(B), IBC 107.2.1, IRC R106.1.2
- **Equipment Specifications** –
NEC 690.4(D), IRC R905.16.1, IRC R905.16.3,
IRC M2302.3, IRC M2302.4, IBC 1505.8,
IBC 1507.17.1, IBC 1507.17.3, IBC 1509.7.2,
IBC 1509.7.4

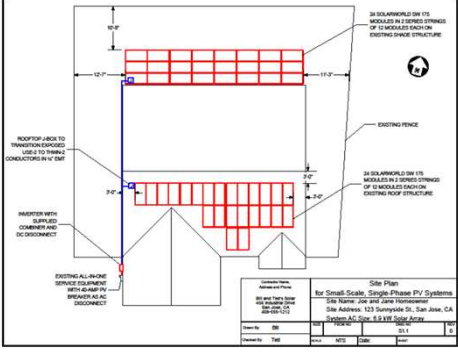
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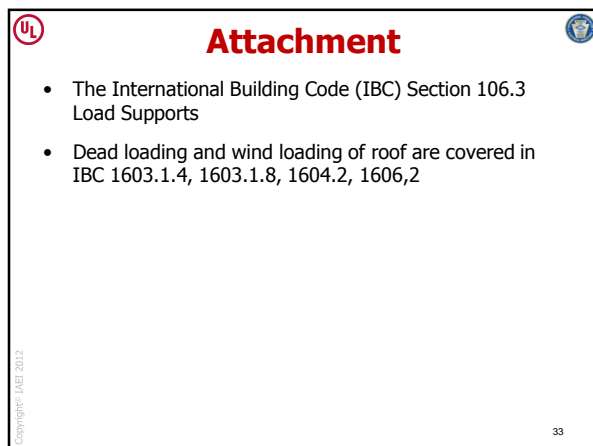
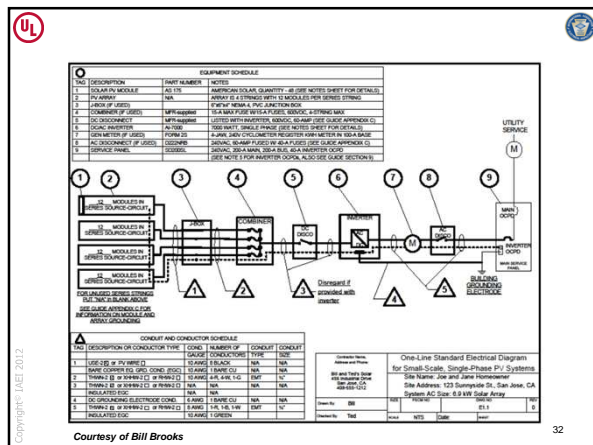
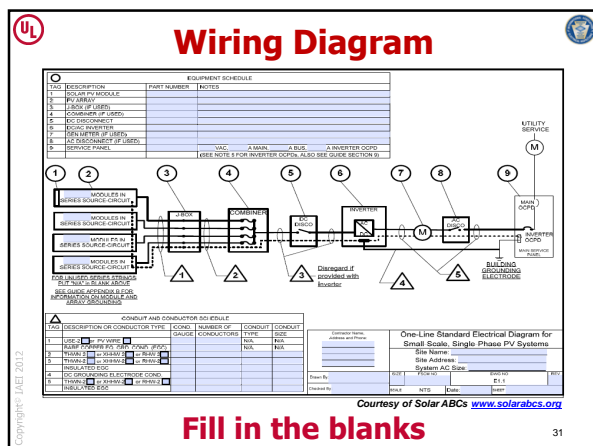
Site Plan

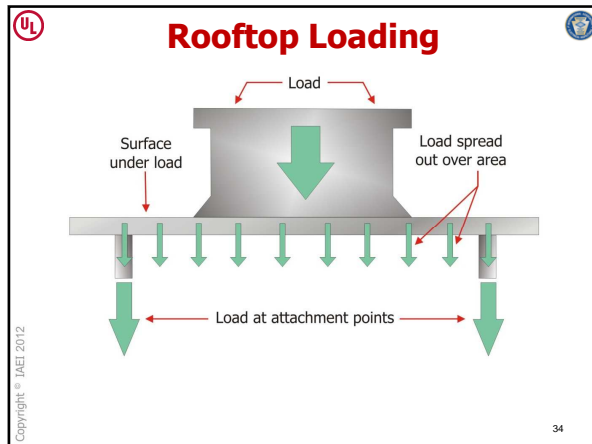


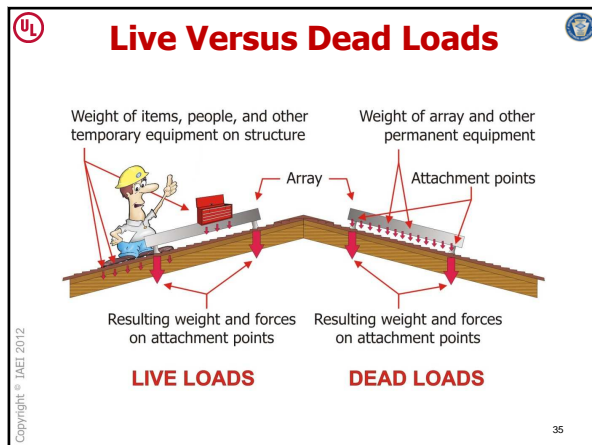


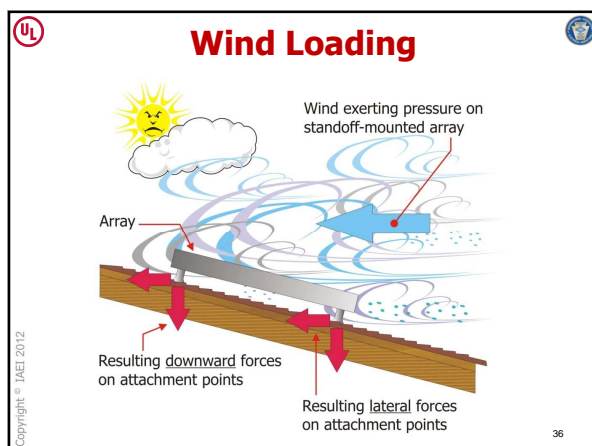
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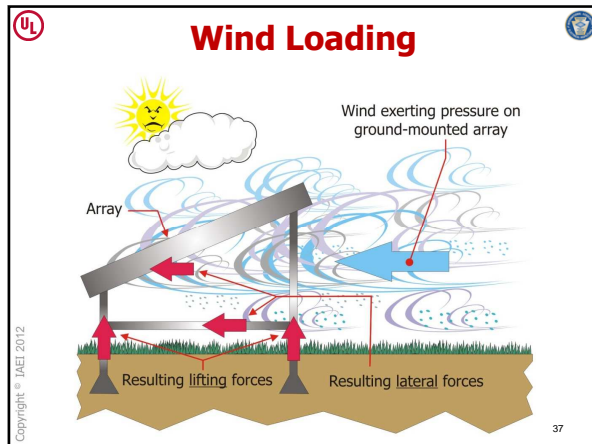
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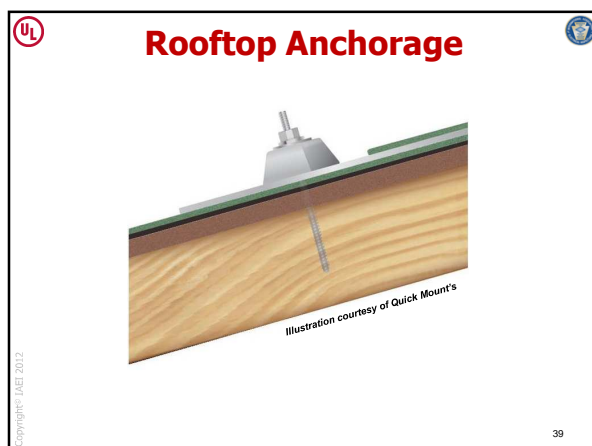


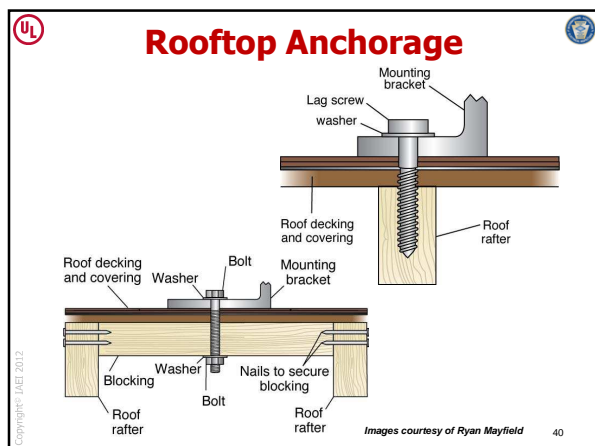












Module Details

bp solar SX 3200 200 watt photovoltaic module

High-efficiency photovoltaic module using silicon nitride multicrystalline silicon cells

Performance

Rated power (P_{max})	200W
Power tolerance	+5%
Nominal voltage	150V
Limited Warranty	25 years

Configuration

8 String frame with output cables and polarized Multicontact (MC) connectors

Electrical Characteristics

	SX 3200	SX 3195
Maximum power (P_{max})	200W	195W
Voltage at P_{max} (V_{mp})	24.5V	24.4
Current at P_{max} (I_{mp})	8.16A	7.96A
Maximum power (P_{max})	192.0W	177.5W
Short-circuit current (I_{sc})	8.7A	8.6A
Open-circuit voltage (V_{oc})	30.0V	30.7V
Temperature coefficient of V_{oc}	-0.005 \pm 0.015 / $^{\circ}$ C	
Temperature coefficient of V_{mp}	-0.11 \pm 0.01 / $^{\circ}$ C	
Temperature coefficient of power	-0.5 \pm 0.02 / $^{\circ}$ C	
NOCT (at 20 $^{\circ}$ C, Sun 0.8kW/m 2 , wind 1m/s)	47 \pm 2 $^{\circ}$ C	
Maximum series fuse rating	15A	
Maximum system voltage	600V U.S. NEC rating	

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41

PV Module Label

MAGE SOLAR

Model Name: MAGE POWERTEC⁺ Plus 185 / 5 MJ

Dimensions: 1580 x 808 x 40 mm

Weight: 15.5 kg

Cell Technology: monocrystalline

Maximum Power (P_{max}): 185 Wp -0/+5 Wp

Voltage at P_{max} : 36.27 V

Current at P_{max} : 5.10 A

Short Circuit Current: 5.50 A

Open Circuit Voltage: 45.00 V

Max. System Voltage: 600 V (VDE certified 1000V)

Fuse Rating: 10 A

NOCT: +47 \pm 2 $^{\circ}$ C

Fire Rating: C

Field Wiring: copper only 12 AWG min. insulated for 90 $^{\circ}$ C min.

All technical data according to standard test condition (STC) irradiation 1000 W/m 2 , Spectrum AM 1.5 and cell temperature 25 $^{\circ}$ C

Module qualified: IEC 61215, IEC 61730, CE, UL, ITT

WARNING - ELECTRICAL HAZARD. This unit produces electricity when exposed to sunlight.

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Inverter Details

Specifications

Inverter Technology

AC Voltage

AC Frequency

DC Input Voltage

Peak Power Tracking Voltage

PV Start Voltage

Maximum DC Input Voltage

Maximum Array Input Power

Maximum AC Power Output

Current THD

Power Factor

Peak Inverter Efficiency

CEC Weighted Efficiency

Cooling

Maximum AC Output Current

Maximum DC Input Current

* Optional external fan (Sunny Breeze) available

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Real sine-wave, current source,

high frequency PWM

210-260 (240 V AC)

59.3 - 60.5 (60 Hz)

(50 Hz also available)

250 - 600 V DC

234 - 480 V DC

300 V DC

233 - 256 V DC

dependent on available line voltage

2600W (240V AC) (DC/DC/CT)

2100W (240V AC)

< 4%

Unity

94.8%

93.0%

*** Convection cooling (no fan)**

12A

12A

UL 1741, E210376, UL 1998, IEEE 519, IEEE 929, ANSI C62.41 C1 & C3, FCC part 15 A & B

International

DIN EN50062 Part 1, 61000-32, 50081, 50014, 600055 Part 2

50011 Group 1 Class B, 50178, 60146 Part 1-1

SMA America, Inc., 12438-C Loma Rica Dr.

Chula Vista, CA 92015

Tel: 530-273-4895 Fax: 530-274-7271

www.sma-america.com

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DC Voltage Ripple

Power Consumption

Ambient Temperature Rating

Enclosure

Dimensions

Weight

UL 1741, E210376, UL 1998, IEEE 519, IEEE 929, ANSI C62.41 C1 & C3, FCC part 15 A & B

United States

International

DIN EN50062 Part 1, 61000-32, 50081, 50014, 600055 Part 2

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Energy Tomorrow

Courtesy of SMA

Equipment Details

PV MODULE RATINGS @ STC (Module Section 2)

Module Name:

Module Model:

Max Power Point Current (I_{mp}):

Max Power Point Voltage (V_{mp}):

Open Circuit Voltage (V_{oc}):

Short Circuit Current (I_{sc}):

Max Series Fuse (Amps):

Max Array Power (P_{max}):

Max Voltage (V_{max}):

VOC Temp Coeff (1/°C):

I_c Coeff Supplied (Circle Units):

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NOTES FOR ALL OWNERS:

DC/DC - OVERCURRENT PROTECTION DEVICE

NATIONAL ELECTRICAL CODE® REFERENCES

INVERTER RATINGS (Module Section 2)

Inverter Name:

Inverter Model:

Max DC Voltage:

Max Power @ DC:

Normal AC Voltage:

Max AC Current:

Max DC/DC Rating:

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DC/DC - OVERCURRENT PROTECTION DEVICE

NATIONAL ELECTRICAL CODE® REFERENCES

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Courtesy of Solar ABCs www.solarabc.org

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Inverter Name:

Inverter Model:

Max DC Voltage:

Max Power @ DC:

Normal AC Voltage:


Max AC Current:

Max DC/DC Rating:


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Energy Tomorrow

Courtesy of Bill Brooks




Key Inspection Points




- Number of PV modules and PV model numbers match plans
- Array conductors and components are installed in a neat and workman like manner
- PV array is properly grounded
- Electrical boxes are accessible and connections are suitable for environment
- Array is fastened and sealed according to attachment detail
- Conductors ratings and sizes match plans

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Key Inspection Points *(cont.)*




- Appropriate signs are properly constructed, installed and displayed, including:
 - Sign identifying PV power source system attributes at dc disconnect
 - Sign identifying ac point of connection
 - Sign identifying switch for alternative power system

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Key Inspection Points *(cont.)*



- Equipment ratings are consistent with application and installed signs on the installation, including:
 - Inverter has a rating as high as max voltage on PV Power Source sign
 - DC-side OCPD's are DC rated at least as high as max voltage on sign
 - Switches and OCPDs are installed according to manufacturers specifications

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Key Inspection Points (cont.)

- Many 600 volt dc switches require passing through the switch poles twice in a specific way

THIS SWITCH IS SUITABLE FOR USE IN ACCORDANCE WITH NEC ARTICLE 690 PHOTOVOLTAIC INSTALLATIONS.

BASIC SWITCH	
NAMEPLATE RATING, 600VDC	ISC RATING, 600VDC
30A	19.2A
60A	38.4A
100A	64.0A
200A	128.0A
400A	256.0A
600A	384.0A

TYPICAL WIRING DIAGRAM

FUSED CONSTRUCTION

NON-FUSED CONSTRUCTION

Photos courtesy of Jeff Fecteau

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Key Inspection Points (cont.)

- Equipment ratings are consistent with application and installed signs on the installation, including:
 - Inverter is rated for the site ac voltage supplied and shown on the ac point of connection sign
 - OCPD connected to the ac output of the inverter is rated at least 125% of maximum current on sign, and is no larger than the maximum OCPD on the inverter listing label
 - Sum of the main OCPD and the inverter OCPD is rated for not more than 120% of the busbar rating

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Key Inspection Points (cont.)

EATON


225 AMP'S MAX. - SEE MAIN BREAKER RATING
225 AMP'S MAX. BUS RATING

EATON

200 AMP'S MAX. - SEE MAIN BREAKER RATING
200 AMP'S MAX. BUS RATING


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Courtesy of Eaton



NEC Article 690


Solar Photovoltaic (PV) Systems



- Part I General
- Part II Circuit Requirements
- Part III Disconnecting Means
- Part IV Wiring Methods
- Part V Grounding
- Part VI Marking
- Part VII Connection to Other Sources
- Part VIII Storage Batteries
- Part IX Systems Over 600 Volts


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NEC Article 705

Interconnected Electric Power Production Sources



- Part I General
- Part II Utility-Interactive Inverters
- Part III Generators

(see Article 705 slides later in presentation)

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Article 690 - Part I General







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NEC Article 690 - Definitions




- **Definitions:**
 - Array
 - Building Integrated Photovoltaics
 - Interactive System
 - Inverter
 - Inverter Output Circuit
 - Module
 - Panel
 - Photovoltaic Output Circuit
 - Photovoltaic Source Circuit
 - Stand-Alone System



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NEC Article 690 - Definitions




Array. A mechanically integrated assembly of modules or panels with a support structure and foundation, tracker, and other components, as required, to form a direct-current power-producing unit.



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NEC Article 690 - Definitions



Building Integrated Photovoltaics. Photovoltaic cells, devices, modules, or modular materials that are integrated into the outer surface or structure of a building and serve as the outer protective surface of that building.

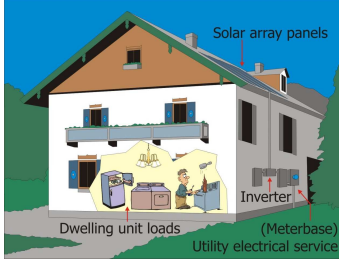



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UL

NEC Article 690 - Definitions

Interactive System. A solar photovoltaic system that operates in parallel with and may deliver power to an electrical production and distribution network. For the purpose of this definition, an energy storage subsystem of a solar photovoltaic system, such as a battery, is not another electrical production source.



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UL

NEC Article 690 - Definitions

Inverter. Equipment that is used to change voltage level or waveform, or both, of electrical energy.

Commonly, an inverter [also known as a power conditioning unit (PCU) or power conversion system (PCS)] is a device that changes dc input to an ac output.

Inverters may also function as battery chargers that use alternating current from another source and convert it into direct current for charging batteries.



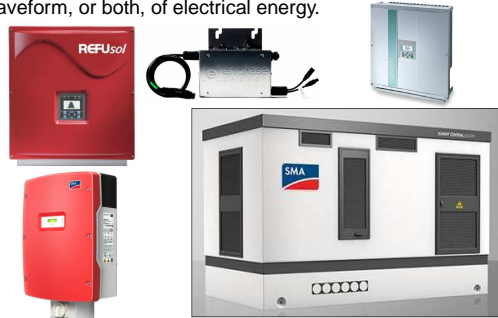
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UL

NEC Article 690 - Definitions

Inverter. Equipment that is used to change voltage level or waveform, or both, of electrical energy.



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NEC Article 690 - Definitions




Module. A complete, environmentally protected unit consisting of solar cells, optics, and other components, exclusive of tracker, designed to generate dc power when exposed to sunlight.



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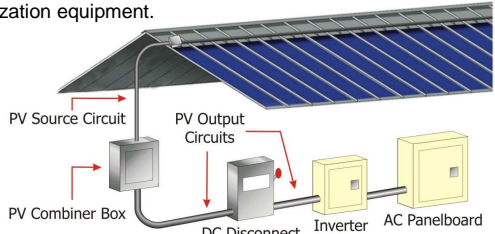


NEC Article 690 - Definitions




Photovoltaic Source Circuit. Circuits between modules and from modules to the common connection point(s) of the dc system.


Photovoltaic Output Circuit. Circuit conductors between the photovoltaic source circuit(s) and the inverter or dc utilization equipment.



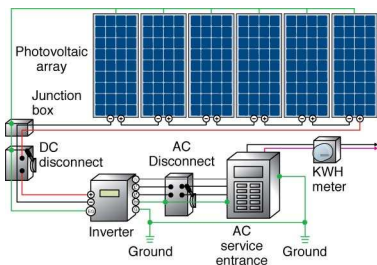
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690.3 Other Articles



- Where the PV system is operated in parallel with a primary source(s) of electricity, the applicable requirements in Article 705 shall apply




**Article 705 Interconnected Electric Power Production Sources*


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Image courtesy of Ryan Mayfield

690.4(A) Photovoltaic Systems

- PV system(s) shall be permitted to supply a building or other structure in addition to any other electricity supply system(s)






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Photo courtesy of DOE/NREL

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690.4(B) Identification & Grouping

- PV circuits (dc/ac) shall not be contained in the same raceway, cable tray, cable, outlet box, junction box, or similar fitting as conductors, feeders, or branch circuits of other non-PV systems, **unless the conductors of the different systems are separated by a partition**





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Photo courtesy of Jeff Fecteau

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690.4(B) Identification & Grouping







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Photo courtesy of Bill McGovern

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690.4(B) Identification & Grouping



- (1) **PV Source Circuits.** ...shall be identified at all points of termination, connection, and splices
- (2) **PV Output and Inverter Circuits.** ...shall be identified at all points of termination, connection, and splices
- (3) **Conductors of Multiple Systems.** ...of more than one PV system occupy the same ... the conductors of each system shall be identified at all termination, connection, and splice points
- (4) **Grouping.** ...of more than one PV system occupy the same junction box or raceway with a removable cover(s), the ac and dc conductors of each system shall be grouped separately by wire ties or similar means at least once, and then shall be grouped at intervals not to exceed 1.8 m (6 ft)

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690.4(D) Equipment




- Inverters, PV modules, combiners, charge controllers and ... shall be identified and listed for the application






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690.4(E) Wiring & Connections



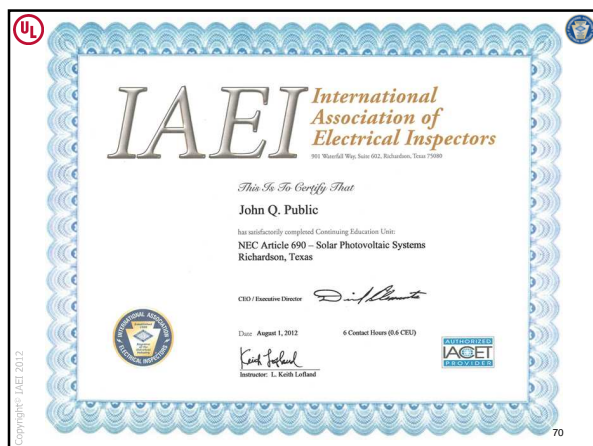
- "Qualified persons" are required to perform the described work on photovoltaic (PV) systems



- **Qualified Person.** One who has skills and knowledge related to the construction and operation of the electrical equipment and installations and has received safety training to recognize and avoid the hazards involved

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NABCEP Recognized PV Training Programs

- UL Knowledge Services
<http://lms.ulknowledgeservices.com/certification>

Knowledge Services

UL Knowledge Services Personnel Certification
With decades of experience in product safety, UL Knowledge Services brings the same dedication to service and commitment to safety to our PV System Installer certification program. The program is designed to ensure that all personnel who install and maintain PV systems have the necessary knowledge and skills to do so safely and effectively.

Certified PV System Installer
The PV System Installer certification program is designed to offer individuals an opportunity to earn recognition upon completion of the program. The program is designed to ensure that all personnel who install and maintain PV systems have the necessary knowledge and skills to do so safely and effectively.

UL 1699B is the first step in this new Personnel Certification program.

Personnel: PV System Installer Training
This is a 4-day, intensive and hands-on course designed for qualified individuals who will be installing and maintaining PV systems. The course includes hands-on training in the installation and maintenance of PV systems.

UL 1703 is the second step in this new Personnel Certification program.

UL 1741 is the third step in this new Personnel Certification program.

UL 2703 is the fourth step in this new Personnel Certification program.

ICC ES AC 365 is the fifth step in this new Personnel Certification program.


**North American Board of Certified Energy Practitioners (NABCEP)*

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Basic PV Standards

- UL 1699B** – Photovoltaic DC Arc-Fault Circuit Protection
- UL 1703** - Flat Plate Photovoltaic Modules and Panels
- UL 1741** - Inverters, Converters, Controllers, and Interconnection System Equipment For Use With Distributed Energy Resources
- UL 2703** - Rack Mounting Systems and Clamping Devices for Flat-Plate Photovoltaic Modules and Panels
- ICC ES AC 365** - Building Integrated Photovoltaic Systems

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UL Product Categories



DIUR - Circuit Breakers, Molded Case and Circuit-breaker Enclosures for Use in Photovoltaic Systems

IZMR - Fuseholders, Photovoltaic

JFGA - Fuses for Photovoltaic System

JDDZ - Cartridge Fuses, Nonrenewable
(Intended for AC circuits only, unless also marked with DC voltage rating)


QIGU - Photovoltaic Modules & Panels

QIKA - Photovoltaic Solar Trackers


QIKH - Photovoltaic Inverters

QIBP - Photovoltaic Charge Controllers

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UL Product Categories



QIIO - Distributed Generation Power Systems Accessory Equipment

QIJL - Distributed Resource Power Systems


QIMS - Photovoltaic Mounting Systems, Mounting Devices, Clamping Devices and Ground Lugs
(Both mounting systems and clamping devices may be for bonding and/or mechanical loading)

QHYZ - AC Modules


QHZK - Building-integrated Photovoltaic Modules & Panels

QHZS - Distributed Generation Wiring Systems and Harnesses

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UL Product Categories



QHZZ - Building-integrated Photovoltaic Mounting Systems

QIIA - Photovoltaic Modules and Panels with System Voltage Ratings above 600 V


WJBE - Switches, Molded Case, for Use in Photovoltaic Systems

WHXX - Switches, Dead-front for Use in Photovoltaic Systems


WIBC - Switches, Enclosed for Use in Photovoltaic Systems

ZKLA - Photovoltaic Wire

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690.4(F) Circuit Routing




- New requirements **were added for visibility and roof marking** of certain PV circuits
- Firefighting community has **expressed concern about the safety of ventilating roofs** where PV circuits are present
- Routing PV circuits along the **building structural members** will **lower probability** that the structural members will be compromised by the firefighting process during a fire
- When PV module system circuits are **integrated into the roof**, PV associated circuits **are to be clearly marked on the surface** of the roof as a visual aid for firefighters and other maintenance personnel

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690.4(H) Multiple Inverters



- PV systems permitted to have multiple utility-interactive inverters installed in or on a single building or structure






Photo courtesy of DOE/NREL

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690.4(H) Multiple Inverters

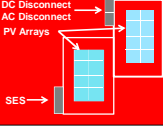


- Where the inverters are remotely located from each other, **a directory** in accordance with 705.10 **shall be installed at each dc PV system disconnecting means, at each ac disconnecting means, and at the main service disconnecting means showing the location of all ac and dc PV system disconnecting means in the building**


CAUTION

SES Equipment also fed from onsite PV System

DC Disconnect
AC Disconnect
PV Arrays



SES






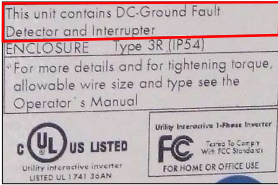
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UL 690.5 Ground-Fault Protection

- Grounded DC PV arrays shall be provided with dc ground-fault protection per 690.5(A) through (C) to reduce fire hazard

Not for personnel protection!
(That would be GFCI protection)




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UL Ground-Fault Protection



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UL 690.5(A) Ground-Fault Detection and Interruption

- Permits automatic opening of the grounded conductor of the faulted circuit
- If the grounded conductor is opened, **all conductors** of the faulted circuit **shall be automatically and simultaneously opened**
- Manual operation of the PV dc disconnect **shall not** activate the GFP or result in the grounded conductors becoming ungrounded

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UL 1741 Overcurrent Protection

- 31.1 Inverters or charge controllers with direct photovoltaic inputs from a grounded photovoltaic array or arrays shall be provided with a ground-fault detector/interrupter (GFDI)
 - Exception No. 1: ac modules are not required to be provided with a GFDI*
 - Exception No. 2: Inverters or charge controllers without GFDI devices may be used when the unit includes the following markings*

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690.5(C) Labels and Markings

- A warning label shall appear on the utility-interactive inverter or be applied by the installer near the ground-fault indicator at a visible location, stating the following:

WARNING
ELECTRIC SHOCK HAZARD
IF A GROUND FAULT IS INDICATED,
NORMALLY GROUNDED
CONDUCTORS MAY BE
UNGROUND AND ENERGIZED

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690.6 Alternating-Current (ac) Modules

- 690.2 Definitions**
 - Alternating-Current (ac) Module (Alternating-Current Photovoltaic Module).** A complete, environmentally protected unit consisting of solar cells, optics, inverter, and other components, exclusive of tracker, designed to generate ac power when exposed to sunlight.
- An ac PV module consists of a single integrated mechanical unit
- Because there is no accessible, field-installed dc wiring in this single unit, the dc PV source-circuit requirements in the NEC are not applicable to the dc wiring in an ac PV module

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690.6 Alternating-Current (ac) Modules

Micro-Inverter

+

PV Module

AC Module

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690.6 Alternating-Current (ac) Modules

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Article 690 Part II Circuit Requirements

Photo courtesy of Jeff Fecteau

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690.7 Maximum Voltage




- One- and Two-Family dwellings maximum is 600 volts
- Other occupancies is unlimited




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690.7 Maximum Voltage



- When open-circuit voltage temperature coefficients are supplied in the instructions for **listed** PV modules, **they shall be used** to calculate the maximum photovoltaic system voltage as required by **110.3(B)** instead of using **Table 690.7**
- These temperature coefficients provide a more accurate maximum system voltage and are required to be used instead of applying Table 690.7
- The *NEC* does not require temperature coefficient information to be included in the installation instructions

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Table 690.7 Voltage Correction Factors for Crystalline and Multicrystalline Silicon Modules *(in part)*



Ambient Temperature (°C)	Factor	Ambient Temperature (°F)
24 to 20	1.02	76 to 68
19 to 15	1.04	67 to 59
14 to 10	1.06	58 to 50
9 to 5	1.08	49 to 41
4 to 0	1.10	40 to 32
-1 to -5	1.12	31 to 23
-6 to -10	1.14	22 to 14
-11 to -15	1.16	13 to 5

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UL

690.8(A) Circuit Sizing

- DC: The **maximum current** shall be the **sum of parallel module rated short-circuit currents** multiplied by 125%

$5.5 \times 1.25 = \mathbf{6.875 \text{ A}}$ maximum current

Maximum Power [P _{max}]	185 Wp	-0/+5 Wp
Voltage at P _{max}	36,27 V	
Current at P _{max}	5,10 A	
Short Circuit Current	5,50 A	
Open Circuit Voltage	45,00 V	
Max. System Voltage	600 V (VDE certificated 1000V)	
Fuse Rating	10 A	
NOCT	+47 +/- 2 °C	
Fire Rating	C	
Field Wiring	copper only 12 AWG min.	insulated for 90° C min.

Photo courtesy of Jeff Fecteau

Reason: PV output circuits can deliver output currents higher than the rated short-circuit currents for more than 3 hours near solar noon

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690.8(A)(3) Circuit Sizing

- AC: The **maximum current** shall be the inverter **continuous output** current rating

➔

Max. continuous output Power* **xxxxx Wac**

Operating voltage range (Vac)*		
MIN	NOMINAL	MAX
XXX	XXX	XXX
Operating frequency range (Hz)*		
MIN	NOMINAL	MAX
XX.X	XX.X	XX.X
Max. continuous output current*		xx Aac

Nameplate courtesy of SMA

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690.8(B)(1) Ampacity

- The circuit conductors and overcurrent devices shall be sized to carry not less than 125 percent of the **maximum currents as calculated in 690.8(A)**

690.8(A) Maximum Circuit Current

SSC $5.50 \times 125 \% = 6.875 \text{ Amps}$

Maximum Power [P _{max}]	185 Wp	-0/+5 Wp
Voltage at P _{max}	36,27 V	
Current at P _{max}	5,10 A	
Short Circuit Current	5,50 A	
Open Circuit Voltage	45,00 V	
Max. System Voltage	600 V (VDE certificated 1000V)	
Fuse Rating	10 A	
NOCT	+47 +/- 2 °C	
Fire Rating	C	
Field Wiring	copper only 12 AWG min.	insulated for 90° C min.


Photo courtesy of Jeff Fecteau

690.8(B)(1) Conductor & OCPD Size


$6.875 \text{ Amps} \times 125\% = \mathbf{8.59 \text{ Amps}}$

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690.8 Circuit Sizing and Current



(D) Where a single overcurrent device is used to protect a set of two or more parallel-connected module circuits, the ampacity of each of the module interconnection conductors shall not be less than the sum of the rating of the single fuse plus 125 percent of the short-circuit current from the other parallel-connected modules






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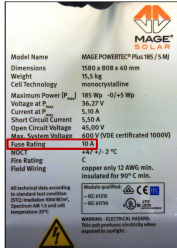


690.9 OCPD for PV Array




- When modules are shaded, back feeding is possible from other parallel strings
 - Result - overheating of modules and wiring
 - Key - proper rated fuse, not exceeding modules' max. fuse rating





Photos courtesy of DOE/NREL and Jeff Fecteau


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Combiner Box





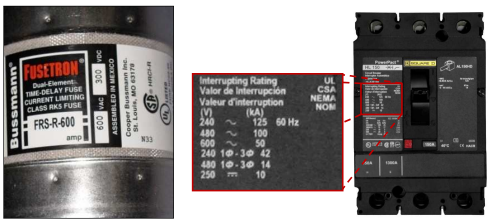


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UL 690.9(D) Direct-Current Rating

- Overcurrent devices, either fuses or circuit breakers, used in any DC portion of a PV power system **shall be listed** for use in DC circuits



Interrupting Rating Valor de Interrupción (I)	(kA)	UL CSA NEMA NOM
240	125	60 Hz
480	100	
600	90	
240 1Ø-3Ø	42	
480 1Ø-3Ø	14	
250	10	

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UL 690.9(D) Direct-Current Rating

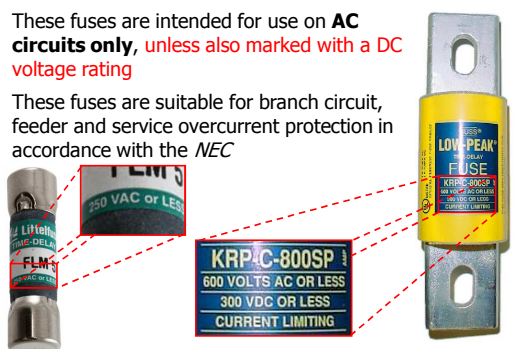
- DC fault currents are considerably harder to interrupt than AC fault currents
- Overcurrent devices **marked or listed only for AC use should not be used in DC circuits**
- Automotive and marine-type fuses, although used in DC systems, are not suitable for use in premise wiring of residential or commercial electrical power systems

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UL Category JDDZ

- These fuses are intended for use on **AC circuits only**, unless also marked with a DC voltage rating
- These fuses are suitable for branch circuit, feeder and service overcurrent protection in accordance with the *NEC*




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690.10 Stand-Alone Systems




- **690.10(E) Back-fed Circuit Breakers.** **Plug-in type** back-fed circuit breakers connected to a stand-alone inverter output in either stand-alone or utility-interactive systems shall be secured in accordance with 408.36(D)


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Back-fed Circuit Breakers




- **690.10(E) Back-fed Circuit Breakers.** Circuit breakers that are marked "line" and "load" shall not be backfed
- **UL 489.** Line and load markings on a circuit breaker are intended to limit connections thereto as marked
- Load markings on a circuit breaker are intended to limit connections


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690.11 Arc-Fault Circuit Protection (Direct Current)




- **AFCI protection (dc)** shall be provided for PV systems with dc source circuits, dc output circuits, or both, on or penetrating a building **operating at a PV system maximum system voltage of 80 volts or greater**
- System shall detect and interrupt arcing faults in the dc PV source and output circuits
- System shall disable or disconnect inverters or charge controllers connected to the fault circuit or system components within the arcing circuit
- Disabled or disconnected equipment shall be manually restarted
- System to have an annunciator that provides a visual indication that the AFCI has operated
- Indication shall not reset automatically


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690.11 Arc-Fault Circuit Protection (Direct Current)





Oper temp range: 40°F to +113°F (-40°C to +45°C)

Contains a DC Ground Fault Detector and Interrupter and a listed Photovoltaic Arc-Fault Circuit Protection of Type 1.

ENCLOSURE Type 3R (IP54)

*For more details and for tightening torque, allowable wire size and type see the Installation Guide.

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Article 690 Part III Disconnection Means







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690.13 All Conductors



- Means shall be provided to disconnect **all current-carrying dc conductors** of a PV system from **all other conductors in a building or other structure**
- A switch, circuit breaker, or other device **shall not be installed in a grounded conductor** if operation of that switch, circuit breaker, or other device leaves the marked, grounded conductor in an ungrounded and energized state

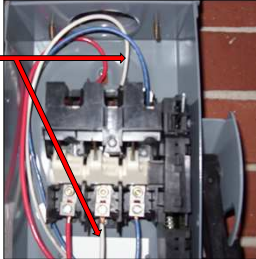




Photo courtesy of James Hathorn

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690.13 All Conductors




- Means shall be provided to disconnect **all current-carrying dc conductors** of a PV system from **all other conductors in a building or other structure**
- Ex. No. 1:** A switch or circuit breaker *that is part of a ground-fault detection system required by 690.5, or that is part of an arc-fault detection/interruption system required by 690.11, shall be permitted to open the grounded conductor when that switch or circuit breaker is automatically opened as a normal function of the device in responding to ground faults*



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690.13 All Conductors




- Means shall be provided to disconnect **all current-carrying dc conductors** of a PV system from **all other conductors in a building or other structure**
- Ex. No. 2:** A disconnecting switch shall be *permitted in a grounded conductor if all of the following conditions are met:*
 - (1) The switch is used only for **PV array maintenance**
 - (2) The switch is accessible only by **qualified persons**
 - (3) The switch is **rated for the maximum dc voltage and current that could be present during any operation, including ground-fault conditions**

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690.14(C) Disconnecting Means



- Means shall be provided to disconnect all conductors in a building or other structure from the PV system conductors

1. ...shall be installed in a **readily accessible location** ... outside of a building or structure or inside nearest the point of entrance...not to be installed in bathrooms




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690.14(C) Disconnecting Means

- Means shall be provided to disconnect all conductors in a building or other structure from the PV system conductors

2. Each PV system disconnecting means shall be permanently marked to identify it as a PV system disconnecting means




Photo courtesy of Bill McGovern


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690.14(C) Disconnecting Means

- Means shall be provided to disconnect all conductors in a building or other structure from the PV system conductors

3. Each PV system disconnecting means shall be suitable for the prevailing conditions




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690.14(C) Disconnecting Means


- Means shall be provided to disconnect all conductors in a building or other structure from the PV system conductors

4. PV disconnecting means shall consist of not more than six switches or six circuit breakers mounted in a single enclosure, in a group of separate enclosures, or in or on a switchboard




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690.14(C) Disconnecting Means




- Means shall be provided to disconnect all conductors in a building or other structure from the PV system conductors

5. PV disconnecting means **shall be grouped** with other disconnecting means for the system... **shall not be required** at the PV module or array location




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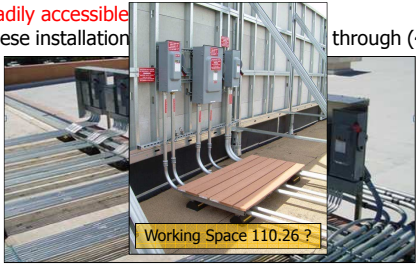
112



690.14(D) Utility-Interactive Inverters Mounted in Not-Readily-Accessible Locations




- Utility-interactive inverters **shall be permitted to be mounted on roofs or other exterior areas that are not readily accessible**
- These installations shall comply with (1) through (4):




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690.14(D) U-I Inverters



- Utility-interactive inverters **shall be permitted to be mounted on roofs or other exterior areas that are not readily accessible**
- These installations shall comply with (1) through (4):
 - (1) A direct-current PV disconnecting means **shall be mounted** within sight of or in the inverter
 - (2) An alternating-current disconnecting means **shall be mounted** within sight of or in the inverter

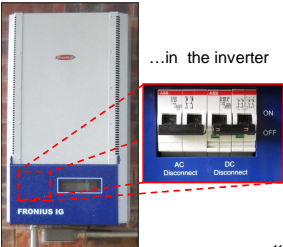


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690.14(D) U-I Inverters

- Utility-interactive inverters shall be permitted to be mounted on roofs or other exterior areas that are not readily accessible
- These installations shall comply with (1) through (4):
 - (1) A direct-current PV disconnecting means shall be mounted within sight of or in the inverter
 - (2) An alternating-current disconnecting means shall be mounted within sight of or in the inverter




...in the inverter

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690.14(D) U-I Inverters

- Utility-interactive inverters shall be permitted to be mounted on roofs or other exterior areas that are not readily accessible
- These installations shall comply with (1) through (4):
 - (3) The ac output conductors from the inverter and an additional ac disconnect for the inverter shall comply with 690.14(C)(1)... (readily accessible location)

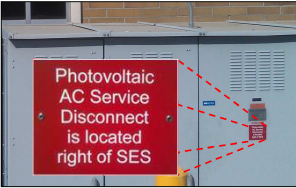


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690.14(D) U-I Inverters


- Utility-interactive inverters shall be permitted to be mounted on roofs or other exterior areas that are not readily accessible
- These installations shall comply with (1) through (4):
 - (4) A plaque shall be installed in accordance with 705.10... (permanent plaque or directory denoting all electric power sources...)



Photos courtesy of Jeff Fecteau


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690.15

Disconnection of PV Equipment



- Means shall be provided to disconnect equipment, such as inverters, batteries, charge controllers, and the like, from all ungrounded conductors of all sources
- If the equipment is energized from more than one source, the disconnecting means **shall be grouped and identified**






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690.16(B) Fuse Servicing



- A disconnecting means **shall be installed on PV output circuits** where fuses **must be serviced that cannot be isolated from energized circuits**
- Shall be **within sight of, and accessible to**, the location of the fuse or integral with fuse holder and **shall comply with 690.17**
- Where located more than 1.8 m (6 ft) from the overcurrent device, **a directory** showing the location of each disconnect **shall be installed at the OCPD location**
- Non-load-break-rated disconnecting means shall be marked **"Do not open under load"**






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690.16(B) Fuse Servicing





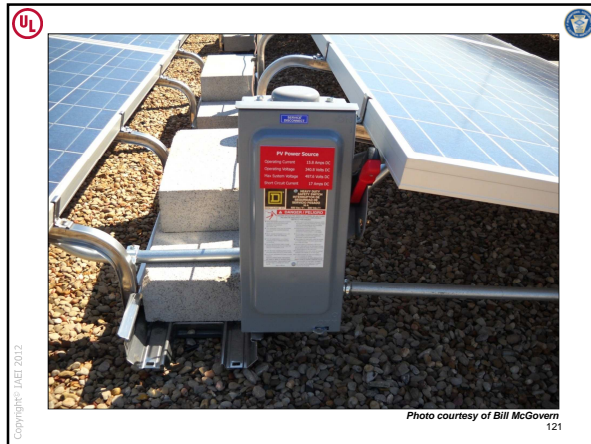


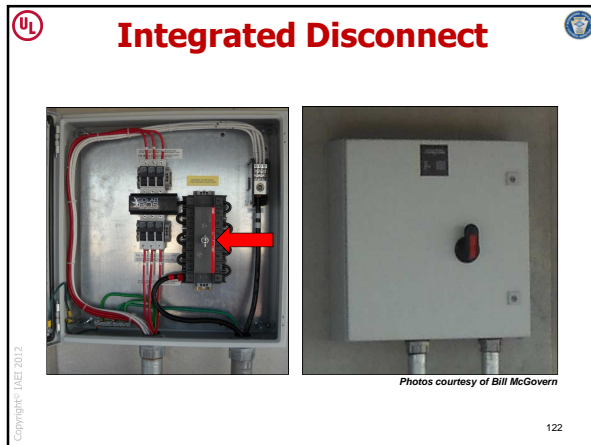


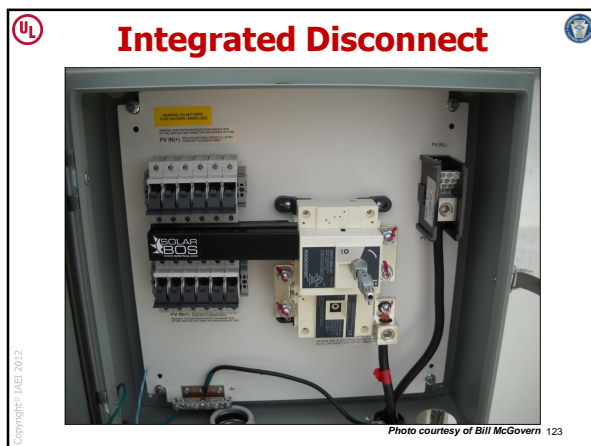
Photos courtesy of Bill McGovern


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Integrated Disconnect







Photo courtesy of Bill McGovern


(Close-up of previous switch)

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690.17 Switch or Circuit Breaker




- The disconnecting means for ungrounded conductors shall consist of a manually operable switch(es) or circuit breaker(s) complying with all of the following requirements:
 - (1) Located where readily accessible
 - (2) Externally operable without exposing the operator to contact with live parts
 - (3) Plainly indicating whether in the open or closed position
 - (4) Having an interrupting rating sufficient for the nominal circuit voltage and the current that is available at the line terminals of the equipment

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690.17 Switch or Circuit Breaker



- Where all terminals of the disconnecting means may be energized in the open position, a warning sign shall be mounted on or adjacent to the disconnecting means
- The sign shall be clearly legible and have the following words or equivalent:

WARNING

ELECTRIC SHOCK HAZARD

DO NOT TOUCH TERMINALS

TERMINALS ON BOTH THE LINE AND LOAD SIDES MAY BE ENERGIZED IN THE OPEN POSITION




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690.17

Switch or Circuit Breaker




- Exception:** A connector *shall be permitted* to be used as an ac or a dc disconnecting means, provided that it complies with the requirements of 690.33 (connectors) and is *listed and identified* for the use






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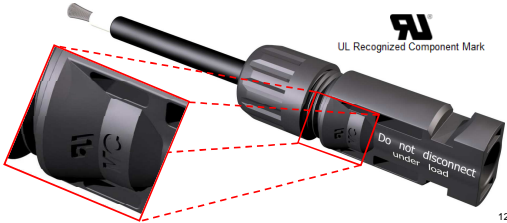



690.17

Switch or Circuit Breaker



- Listed and identified for the use
- The UL Recognized Component Mark *does not provide evidence* of listing or labeling, which may be required by installation codes or standards





UL Recognized Component Mark

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Article 690


Part IV Wiring Methods






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690.31(A) Wiring Systems



- All raceway and cable wiring methods included in the *NEC* and other wiring systems and fittings **specifically intended and identified** for use on PV arrays shall be permitted
- **Informational Note:** PV modules operate at elevated temperatures when exposed to high ambient temperatures and to bright sunlight





Photo courtesy of Bill McGovern

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690.31(B) Single-Conductor Cable




- Single-conductor cable type **USE-2**, and single-conductor cable **listed and labeled as PV wire** shall be permitted in exposed outdoor locations in PV source circuits for PV module interconnections within the PV array




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690.31(E) Direct-Current PV Source and Output Circuits Inside a Building



- Where **dc PV source or output circuits** from a building-integrated or other PV system are run inside a building or structure, they **shall be contained** in the following wiring methods:
 - Metal raceways
 - Type MC metal-clad cable that complies with 250.118(10) (*for EGC*)
 - Metal enclosures
- Shall comply from the point of penetration of the surface of the building or structure to the first readily accessible disconnecting means

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690.31(E) Direct-Current PV Source and Output Circuits Inside a Building





Photo courtesy of Jeff Simpson

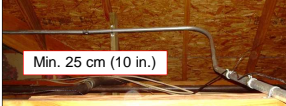
133

690.31(E)(1) Beneath Roofs



Minimum 25 cm (10 in.) below roof decking

- Wiring methods shall not be installed within 25 cm (10 in.) of the roof decking or sheathing except where directly below the roof surface covered by PV modules and associated equipment
- Circuits shall be run perpendicular to the roof penetration point to supports a minimum of 25 cm (10 in.) below the roof decking



Min. 25 cm (10 in.)

Photos courtesy of Bill McGovern

134

690.31(E)(2) Flexible Wiring Methods

- Where FMC smaller than MD 21 (trade size $\frac{3}{4}$) or Type MC cable smaller than 25 mm (1 in.) in diameter containing PV power circuit conductors is installed across ceilings or floor joists, the raceway or cable shall be protected by substantial guard strips that are at least as high as the raceway or cable
- Where run exposed, other than within 1.8 m (6 ft) of their connection to equipment, these wiring methods shall closely follow the building surface or be protected from physical damage by an approved means






Photo courtesy of Jeff Simpson

135




690.31(E)(3)

Marking or Labeling Required




- The following wiring methods and enclosures that contain PV power source conductors shall be marked with the wording “**Photovoltaic Power Source**” by means of permanently affixed labels or other approved permanent marking:
 - (1) Exposed raceways, cable trays, and other wiring methods
 - (2) Covers or enclosures of pull boxes and junction boxes
 - (3) Conduit bodies in which any of the available conduit openings are unused

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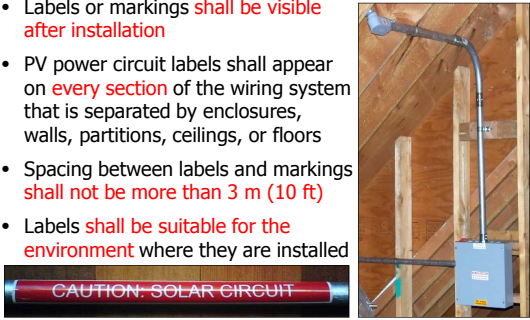


690.31(E)(4)


Marking and Labeling



- Labels or markings shall be visible after installation
- PV power circuit labels shall appear on **every section** of the wiring system that is separated by enclosures, walls, partitions, ceilings, or floors
- Spacing between labels and markings shall not be more than 3 m (10 ft)
- Labels shall be suitable for the environment where they are installed



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690.31(F)


Flexible, Fine-Stranded Cables





- Flexible, fine-stranded cables shall be terminated only with terminals, lugs, devices, or connectors in accordance with 110.14(A)

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690.31(F)
Flexible, Fine-Stranded Cables

14	19/0.0147
12	19/0.0185
10	27/24
8	37/24
6	61/24
4	105/24
2	154/24

Photo courtesy of T&B

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690.33 Connectors

- The connectors permitted by Article 690 shall comply with 690.33(A) through (E):
 - (A) Configuration. The connectors shall be polarized and shall have a configuration that is noninterchangeable with receptacles in other electrical systems on the premises
 - (B) Guarding. The connectors shall be constructed and installed so as to guard against inadvertent contact with live parts by persons

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690.33 Connectors (cont.)


- The connectors permitted by Article 690 shall comply with 690.33(A) through (E):
 - (C) Type. The connectors shall be of the latching or locking type
 - Connectors that are readily accessible and that are used in circuits operating at over 30 volts, nominal, maximum system voltage for dc circuits, or 30 volts for ac circuits, shall require a tool for opening
 - (D) Grounding Member. The grounding member shall be the first to make and the last to break contact with the mating connector

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690.33 Connectors




- The connectors permitted by Article 690 shall comply with 690.33(A) through (E):
 - (E) Interruption of Circuit. Connectors shall be either (1) or (2):
 - (1) Be **rated for interrupting current** without hazard to the operator
 - (2) Be a type that **requires the use of a tool to open and marked** “Do Not Disconnect Under Load” or “Not for Current Interrupting”




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UL Category QI/Q2 Recognized Component




- ... may consist of in-line connectors, panel-mounted connectors, distribution blocks and splitter connectors for the purpose of facilitating connections up to and including inverters, combiner boxes, and like devices in a PV system
- They are not intended to be used on the **output side of inverters and combiner boxes or to downstream system components** from such devices




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690.35 Ungrounded PV Power Systems



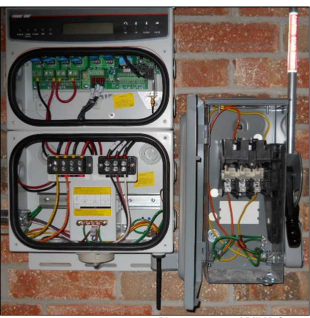



Photo courtesy of Bill McGovern


- PV Power systems **shall be permitted** to operate with ungrounded PV source and output circuits where the system complies with 690.35(A) through (G):

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690.35 Ungrounded PV Power Systems




- PV Power systems **shall be permitted** to operate with ungrounded PV source and output circuits where the system complies with 690.35(A) through (G):
 - **(A) Disconnects.** All photovoltaic source and output circuit conductors **shall have disconnects** complying with 690, Part III
 - **(B) Overcurrent Protection.** All photovoltaic source and output circuit conductors **shall have overcurrent protection** complying with 690.9

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690.35 Ungrounded PV Power Systems *(cont.)*




- PV Power systems **shall be permitted** to operate with ungrounded PV source and output circuits where the system complies with 690.35(A) through (G):
 - **(C) Ground-Fault Protection.** All PV source and output circuits **shall be provided** with a ground-fault protection device or system that complies with (1) through (3):
 - (1) Detects a ground fault
 - (2) Indicates that a ground fault has occurred
 - (3) Automatically disconnects all conductors or causes the inverter or charge controller connected to the faulted circuit to automatically cease supplying power to output circuits

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690.35 Ungrounded PV Power Systems *(cont.)*




- PV Power systems **shall be permitted** to operate with ungrounded PV source and output circuits where the system complies with 690.35(A) through (G):
 - **(D)** The photovoltaic source conductors shall consist of the following:
 - (1) Nonmetallic jacketed multiconductor cables
 - (2) Conductors installed in raceways, or
 - (3) Conductors listed and identified as Photovoltaic (PV) Wire installed as exposed, single conductors

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690.35 Ungrounded PV Power Systems (cont.)



- PV Power systems **shall be permitted** to operate with ungrounded PV source and output circuits where the system complies with 690.35(A) through (G):
 - **(F)** The PV power source **shall be labeled** with the following warning at each junction box, combiner box, disconnect, and device where energized, ungrounded circuits may be exposed during service:


WARNING

ELECTRIC SHOCK HAZARD


THE DC CONDUCTORS OF THIS PHOTOVOLTAIC SYSTEM ARE UNGROUNDED AND MAY BE ENERGIZED

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690.35 Ungrounded PV Power Systems (cont.)




- PV Power systems **shall be permitted** to operate with ungrounded PV source and output circuits where the system complies with 690.35(A) through (G):
 - **(G)** The inverters or charge controllers used in systems with ungrounded PV source and output circuits **shall be listed for the purpose**


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690.35 Ungrounded PV Power Systems







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Article 690 - Part V Grounding







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151

690.42 Point of System Grounding Connection



- The DC circuit grounding connection shall be made at **any single point** on the photovoltaic output circuit
 - **Exception:** Systems with a 690.5 GFP device shall be permitted to have the required grounded conductor-to-ground bond made at the GFP device
 - This bond, where internal to the GFP equipment, shall not be duplicated with an external connection
- **Note:** Locating the grounding connection point as close as practicable to the PV source better protects the system from voltage surges due to lightning

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690.43 Equipment Grounding

- Equipment grounding conductors and devices shall comply with 690.43(A) through (F):
 - **(A) Equipment Grounding Required.** Exposed non-current-carrying metal parts of module frames, equipment, and conductor enclosures **shall be grounded** in accordance with 250.134 or 250.136(A) regardless of voltage

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690.43 Equipment Grounding




- Equipment grounding conductors and devices shall comply with 690.43(A) through (F):
 - **(B) Equipment Grounding Conductor Required.**
An equipment grounding conductor between the PV array and other equipment shall be required in accordance with 250.110





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690.43 Equipment Grounding




- Equipment grounding conductors and devices shall comply with 690.43(A) through (F):
 - **(C) Structure as Equipment Grounding Conductor.** Devices **listed and identified for grounding** the metallic frames of PV modules or other equipment **shall be permitted** to bond the exposed metal surfaces or other equipment to mounting structures
 - Metallic mounting structures, other than building steel, used for grounding purposes **shall be identified** as equipment-grounding conductors **or shall have identified bonding jumpers** or devices connected between the separate metallic sections and shall be bonded to the grounding system

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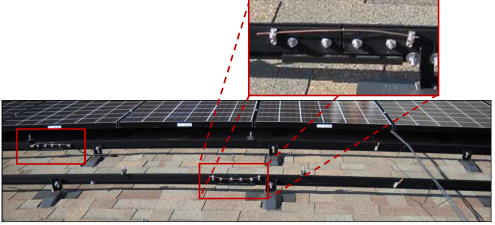
155



690.43 Equipment Grounding



- Equipment grounding conductors and devices shall comply with 690.43(A) through (F):
 - **(C) Structure as Equipment Grounding Conductor.** ...**listed and identified for grounding**...



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690.43 Equipment Grounding







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690.43 Equipment Grounding



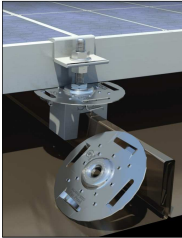
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158

UL 2703 Use and Installation

- PV mounting systems, mounting devices, clamping devices and ground lugs are intended for use with **specific PV modules and panels, specified module frames, mounting structures** as identified in the individual certifications
- Mounting systems and clamping devices **may be investigated** for mechanical mounting alone, or **mechanical mounting and ground bonding** as identified in the individual certifications
- Ground lugs **may be investigated** for use with **specific PV modules, specific PV module frames, or specific mounting-system rails**



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159

690.43 Equipment Grounding

- Equipment grounding conductors and devices shall comply with 690.43(A) through (F):
 - **(E) Adjacent Modules.** Devices **identified and listed** for bonding the metallic frames of PV modules **shall be permitted** to bond the exposed metallic frames of PV modules to adjacent PV modules
- Concerns:

Exposed terminations




Photo courtesy Bill Brooks

Dissimilar metals




Photo courtesy Rhonda Parkhurst

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690.45(A) Size of EGCs

- Where **protected by GFP** per 690.5, the min. size for equipment grounding conductors **shall be** in per 250.122

Rating or Setting of Automatic Overcurrent Device in Circuit Ahead of Equipment, Conduit, etc., Not Exceeding (Amperes)	Size (AWG or kcmil)	
	Copper	Aluminum or Copper-Clad Aluminum
15	14	12
20	12	10
60	10	8
100	8	6
200	6	4
300	4	2
400	3	1
500	1	1/0
600	1/0	2/0

Note: Where necessary to comply with 250.4(A)(5) or 250.4(B)(4), the equipment grounding conductor shall be sized larger than given in this table.
 * See installation restrictions in 250.120 (in part)

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690.46 Array EGCs

- Equipment grounding conductors for PV modules smaller the 6 AWG shall comply with 250.120(C)




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690.47(C)

Grounding Electrode System

• **(C) Systems with Alternating-Current and Direct-Current Grounding Requirements.** PV systems having dc and ac circuits shall have the dc grounding system bonded to the ac grounding system by one of the following (3) methods:

- (1) **Separate** Direct-Current Grounding Electrode System Bonded to the Alternating-Current Grounding Electrode System

1. Sized on the larger of the ac GEC or the dc GEC per 250.166

2. Not a substitute for ac EGC

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690.47(C)

Grounding Electrode System

• **(C) Systems with Alternating-Current and Direct-Current Grounding Requirements.** PV systems having dc and ac circuits shall have the dc grounding system bonded to the ac grounding system by one of the following (3) methods:

- (2) **Common** Direct-Current and Alternating-Current Grounding Electrode

1. Sized per 250.166

2. Not a substitute for ac EGC

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690.47(C)

Grounding Electrode System

• **(C) Systems with Alternating-Current and Direct-Current Grounding Requirements.** PV systems having dc and ac circuits shall have the dc grounding system bonded to the ac grounding system by one of the following (3) methods:

- (3) **Combined** Direct-Current Grounding Electrode Conductor and Alternating-Current Equipment Grounding Conductor

1. Unspliced, or irreversibly spliced

2. The larger of 250.122 or 250.166

3. Installed in per 250.64(E)

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Article 690 - Part VI Marking







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690.53 Direct-Current Photovoltaic Power Source




- A permanent label for the direct-current PV power source indicating items (1) through (5) **shall be provided** by the installer at the PV disconnecting means:

- (1) Rated maximum power-point current
- (2) Rated maximum power-point voltage
- (3) Maximum system voltage
- (4) Short-circuit current
- (5) Maximum rated output current of the charge controller (if installed)




RATED MAX POWER-POINT CURRENT	15.8 AMPS
RATED MAX POWER-POINT VOLTAGE	357.6 VDC
MAXIMUM SYSTEM VOLTAGE	553.5 VDC
SHORT CIRCUIT CURRENT	16.92 VDC
MAX RATED OUTPUT CURRENT OF THE CHARGE CONTROLLER IF INSTALLED	N/A

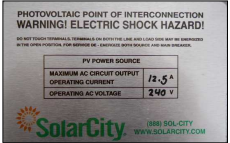
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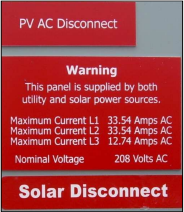


690.54 Interactive System Point of Interconnection




- All** interactive system(s) points of interconnection with other sources **shall be marked** at an accessible location at the disconnecting means as a power source and with the rated ac output current and the nominal operating ac voltage






Photos courtesy of Bill McGovern



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690.56 Identification of Power Sources




- **(B) Facilities with Utility Services and PV Systems.** Buildings or structures with both utility service and a PV system **shall have a permanent plaque or directory** providing the location of the service disconnecting means and the PV system disconnecting means **if not located at the same location**.








Photos courtesy of Rhonda Parkhurst

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Article 690 - Part VII Connection to Other Sources




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690.64 Point of Connection



- Point of connection **shall be in accordance** with 705.12
- **705.12 Point of Connection.** The output of an interconnected electric power source shall be connected as specified in (A), (B), (C), or (D):
 - (A) Supply Side
 - (B) Integrated Electrical Systems
 - (C) Greater Than 100 kW
 - (D) Utility-Interactive Inverters



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 **NEC Article 705** 

Interconnected Electric Power Production Sources



- Part I General
- Part II Utility-Interactive Inverters
- Part III Generators

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 **705.12(A) Point of Connection** 

- **705.12 Point of Connection.** The output of an interconnected electric power source shall be connected as specified in (A), (B), (C), or (D):
 - **(A) Supply Side.** An electric power production source shall be permitted to be connected to the supply side of the service disconnecting means as permitted in 230.82(6)
 - The sum of the ratings of all OCPD's connected to power production sources **shall not exceed the rating of the service**


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 **705.12(D)** 

Utility-Interactive Inverters


- **705.12 Point of Connection.** The output of an interconnected electric power source shall be connected as specified in (A), (B), (C), or (D):
 - **(D) Utility-Interactive Inverters.** Output of a utility-interactive inverter **shall be permitted** to be connected to the load side of the service disconnecting means
 - Where distribution equipment is fed simultaneously by a primary source(s) and one or more utility-interactive inverters, the interconnecting provisions for the utility-interactive inverter(s) **shall comply with** (D)(1) through (D)(7):

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705.12(D)


Utility-Interactive Inverters



- (1) Each source interconnection **shall be made** at a dedicated circuit breaker or fusible disconnecting means
- (2) The sum of the ampere ratings of overcurrent devices in circuits supplying power to a busbar or conductor **shall not exceed** 120% of the busbar or conductor




225 AMPS MAX. - SEE MAIN BREAKER RATING.
225 AMPS MAX. BUS RATING




Photos courtesy of Jeff Fecteau

175




705.12(D)

Utility-Interactive Inverters




- (3) The interconnection point **shall be on** the line side GFP
- (4) Equipment containing overcurrent devices in circuits supplying power to a busbar or conductor supplied from multiple sources **shall be marked** to indicate the presence of all sources


PHOTOVOLTAIC POWER SOURCE
BREAKERS ARE BACKFED
MAXIMUM AC CURRENT 144A
SYSTEM AC VOLTAGE 240V



SERVICE DISCONNECT




176


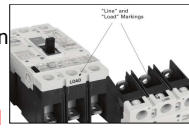


705.12(D)

Utility-Interactive Inverters




- (5) Circuit breakers, if backfed, **shall be suitable** for such operation
- (6) **Listed** plug-in-type circuit breakers backfed from utility-interactive inverters that are **listed and identified as interactive** shall be permitted to omit the additional fastener normally required by 408.36(D) for such applications





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177



705.12(D) Utility-Interactive Inverters




- (7) ... a connection in a panelboard shall be positioned at the opposite (load) end from the input feeder location or main circuit location
- A permanent warning label shall be applied to the distribution equipment with the following wording or equivalent:




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UL 1741 Utility Interaction




- **UL 1741 - Inverters, Converters, Controllers and Interconnection System Equipment for Use With Distributed Energy Resources**
- Prevention of exporting power after utility outage ("anti-islanding")
- Addresses:
 - Shock hazards to utility line crews
 - Current contribution to the utility fault
 - Potential problems in re-energizing the line
 - Damage to equipment if line re-energized out of sync with the inverter

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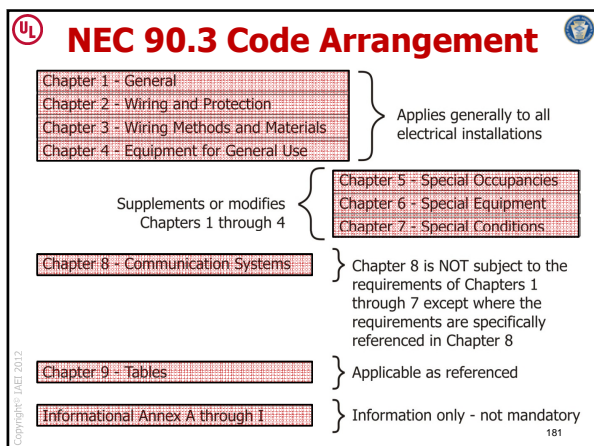
NEC Applications to PV Installations

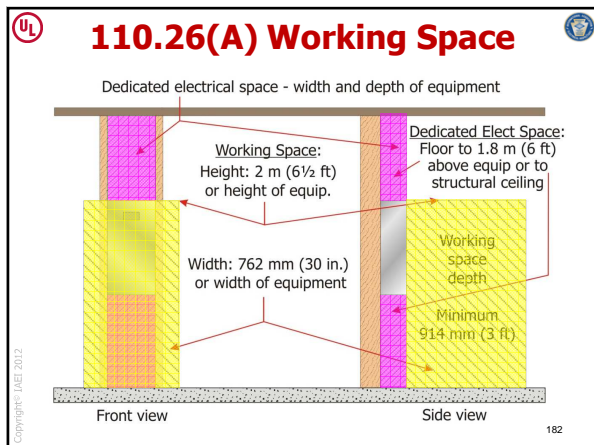


- Article 690 is not the only section of the *NEC* applicable to PV Installations
- Knowledge of the structure of the *NEC* is a must for PV installers and enforcers
- See *NEC* 90.3 and Figure 90.3

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UL Table 110.26(A)(1) Working Space

Nominal Voltage to Ground	Minimum Clear Distance		
	Condition 1	Condition 2	Condition 3
0-150	914 mm (3 ft)	914 mm (3 ft)	914 mm (3 ft)
151-600	914 mm (3 ft)	1.07 m (3½ ft)	1.22 m (4 ft)

Condition 1 Live parts one side, insulated or ungrounded parts other side


Condition 2 Live parts one side, grounded parts on the other side

Condition 3 Live parts on both sides of the work space


The requirements in Conditions 1, 2, and 3 to Table 110.26(A)(1) must be applied to establish the minimum depth of working space required in front of electrical equipment

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183



200.6(A)(6) Means of Identifying Grounded Conductors




- A single-conductor, sunlight-resistant, outdoor-rated cable used as a grounded conductor in photovoltaic power systems, as permitted by 690.31, in sizes 6 AWG and smaller shall be identified at the time of installation by distinctive white marking at all terminations




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250.97 Bonding for Over 250 Volts




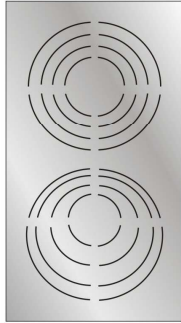
- For circuits of over 250 volts to ground, where oversized concentric, or eccentric knockouts are encountered "Listed Fittings" are required to provide a reliable bonding connection
- Bonding jumpers shall be used around impaired connections, such as reducing washers or oversized, concentric, or eccentric knockouts at service equipment regardless of the voltage *[see 250.92(B)]*

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Concentric and Eccentric Knockouts





Concentric knockouts



May be necessary to bond around concentric knockouts to ensure current-carrying capacity

Bonding jumpers required around impaired connections such as reducing washers, concentric or eccentric knockouts

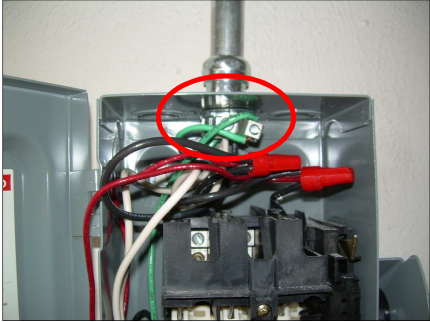
Eccentric knockouts

Eccentric rings present the same obstacle to carrying fault current as concentric knockouts

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250.97 Bonding for Over 250 Volts



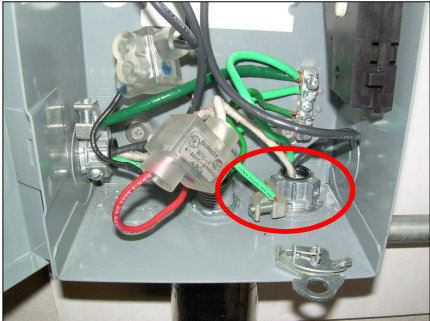
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250.97 Bonding for Over 250 Volts



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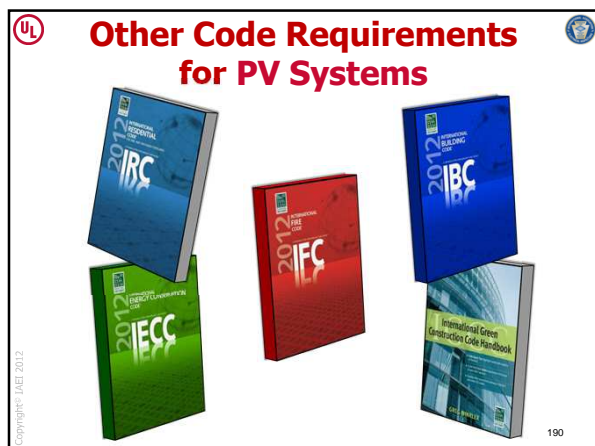
Conduit Exposed to Sunlight Above Rooftops
Table 310.15(B)(2)(c)



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- 601.2 Permits**
Permits shall be obtained for refrigeration systems, battery systems and PV power systems as set forth in Sections 105.6 and 105.7
- 605.11 Solar Photovoltaic Power Systems**
PV power systems shall be installed in accordance with Sections 605.11.1 through 605.11.4, the International Building Code and the NEC
 - Exception:** Detached, nonhabitable Group U structures including, but not limited to, parking shade structures, carports, solar trellises and similar structures shall not be subject to the requirements of this section


191

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- 605.11.1 Marking**
 - Marking is required on interior and exterior DC conduit, enclosures, raceways, cable assemblies, junction boxes, combiner boxes and disconnects
- 605.11.1.1 Materials**
 - The materials used for marking shall be reflective, weather resistant and suitable for the environment
 - Marking as required in Sections 605.11.1.2 through 605.11.1.4 shall have all letters capitalized with a minimum height of 10 mm (3/8 in.) white on red background

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192



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- **605.11.1.2 Marking Content**
 The marking **shall contain the words**
 "WARNING: PHOTOVOLTAIC POWER SOURCE"
- **605.11.1.3 Main Service Disconnect**
 The marking **shall be placed** adjacent to the main service disconnect in a location clearly visible from the location where the disconnect is operated




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- **605.11.1.4 Location of Marking**
Marking shall be placed on interior and exterior DC conduit, raceways, enclosures and cable assemblies **every 3.0 m (10 ft), within 300 mm (1 ft) of turns or bends and within 30 mm (1 ft) above and below penetrations** of roof/ceiling assemblies, walls or barriers




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- **605.11.2 Locations of DC Conductors**


 - Conduit, wiring systems, and raceways for PV circuits **shall be located as close as possible** to the ridge or hip or valley and from the hip or valley as directly as possible to an outside wall to **reduce trip hazards** and **maximize ventilation opportunities**
 - Conduit runs between sub arrays and to DC combiner boxes **shall be installed in a** manner that minimizes the total amount of conduit on the roof by **taking the shortest path** from the array to the DC combiner box

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- **605.11.2 Locations of DC Conductors (cont.)**
 - The DC combiner boxes **shall be located** such that conduit runs are minimized in the pathways between arrays
 - DC wiring **shall be installed** in metallic conduit or raceways when located within enclosed spaces in a building
 - Conduit **shall run along the bottom** of load bearing members

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- **605.11.3 Access and Pathways**

Roof access, pathways, and spacing requirements **shall be provided in accordance** with Sections 605.11.3.1 through 605.11.3.3.3

 - **Exception No. 1.** Residential structures **shall be designed** so that each photovoltaic array is **no greater than 45 m (150 ft) by 45 m (150 ft) in either axis**
 - **Exception No. 2.** Panels/modules **shall be permitted** to be located up to the roof ridge where an alternative ventilation method **approved by the fire chief** has been provided or where the fire chief has determined vertical ventilation techniques will not be employed

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- **605.11.3.1 Roof Access Points**

Roof access points **shall be located in areas** that do not require the placement of ground ladders over openings such as windows or doors, and located at strong points of building construction in locations where the access point does not conflict with overhead obstructions such as tree limbs, wires, or signs

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- **605.11.3.2 Residential Systems for One- and Two-Family Dwellings**
Access to residential systems for one- and two-family dwellings **shall be provided** in accordance with Sections 605.11.3.2.1 through 605.11.3.2.4




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- **605.11.3.2.1 Residential Buildings with Hip Roof Layouts**
 - PV panels/modules installed on residential buildings with hip roof layouts **shall be located** in a manner that provides a **900 mm (3 ft) wide** clear access pathway from the eave to the ridge on each roof slope where PV panels/modules are located
 - The access pathway **shall be located** at a structurally strong location on the building capable of supporting the live load of fire fighters accessing the roof
 - *Exception: These requirements **shall not apply** to roofs with slopes of two units vertical in 12 units horizontal (2:12) or less*

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- Hip roofs need one a **900 mm (3 ft) wide** clear access pathway from the eave to the ridge on each roof slope **where PV panels/modules are located**




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- **605.11.3.2.2 Residential Buildings with a Single Ridge**
 - PV panels/modules installed on residential buildings with a single ridge **shall be located** in a manner that provides **two, 900 mm (3 ft) wide** access pathways from the eave to the ridge on each roof slope where PV panels/modules are located
 - *Exception: This requirement **shall not apply** to roofs with slopes of two units vertical in 12 units horizontal (2:12) or less*

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- Ridge roofs need **two, 900 mm (3 ft) wide access pathways** from the eave to the ridge






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- **605.11.3.2.3 Residential Buildings with Roof Hips and Valleys**
 - PV panels/modules installed on residential buildings with roof hips and valleys **shall be located no closer than 450 mm (18 in.)** to a hip or a valley **where panels/modules are to be placed on both sides of a hip or valley**
 - Where panels are to be located on **only one side of a hip or valley** that is of **equal length**, the panels **shall be permitted** to be placed directly adjacent to the hip or valley
 - ***Exception:** These requirements **shall not apply** to roofs with slopes of two units vertical in 12 units horizontal (2:12) or less*

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- Residential buildings with PV panels placed on both sides of a hip or valley, they **shall not be located closer than 450 mm (18 in.) to a hip or a valley**






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- Roofs with hips and valleys, with **PV panels only one side of a hip or valley** that is of equal length, the **panels shall be permitted** to be placed directly adjacent to the hip or valley






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- 605.11.3.2.4 Residential Building Smoke Ventilation**
PV panels installed on residential buildings **shall be located no higher than 900 mm (3 ft) below the ridge** in order to allow for fire department smoke ventilation operations






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- **605.11.3.3 Other Than Residential Buildings**
 Access to systems for occupancies **other than one- and two-family dwellings** shall be provided in accordance with Sections 605.11.3.3.1 through 605.11.3.3.3
 - **Exception:** *Where it is determined by the fire code official that the roof configuration is similar to that of a one- or two-family dwelling, the residential access and ventilation requirements in Sections 605.11.3.2.1 through 605.11.3.2.4 shall be permitted to be used*

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- **605.11.3.3.1 Access**
 There shall be a minimum 1.8 m (6 ft) wide clear perimeter around the edges of the roof
 - **Exception:** *Where either axis of the building is 75 m (250 ft) or less, there shall be a minimum 1.2 m (4 ft) wide clear perimeter around the edges of the roof*






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- **605.11.3.3.2 Pathways**
 - The PV installation shall be designed to provide designated pathways
 - The pathways shall meet the following requirements:
 1. The pathway shall be over areas capable of supporting the live load of fire fighters accessing the roof
 2. The centerline axis pathways shall be provided in both axes of the roof


Centerline axis pathways shall run where the roof structure is capable of supporting the live load of fire fighters accessing the roof

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- **605.11.3.3.2 Pathways (cont.)**
 - The PV installation shall be designed to provide designated pathways
 - The pathways shall meet the following requirements:
 3. Shall be a straight line not less than 1.2 m (4 ft) clear to skylights or ventilation hatches
 4. Shall be a straight line not less than 1.2 m (4 ft) clear to roof standpipes
 5. Shall provide not less than 1.2 m (4 ft) clear around roof access hatch with at least one not less than 1.2 m (4 ft) clear pathway to parapet or roof edge

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- **605.11.3.3.3 Smoke Ventilation**

The PV installation shall be designed to meet the following requirements:

 - 1. Arrays shall be no greater than 45 m (150 ft) by 45 m (150 ft) in distance in either axis in order to create opportunities for fire department smoke ventilation operations

Not greater than
150 ft by 150 ft



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UL **2012 IFC - PV Systems**

- **605.11.3.3 Smoke Ventilation**
The PV installation shall be designed to meet the following requirements:
 - 2. Smoke ventilation options between array sections shall be one of the following:
 - 2.1. A pathway 2.5 m (8 ft) or greater in width
 - 2.2. A 1.2 m (4 ft) or greater in width pathway and bordering roof skylights or smoke and heat vents
 - 2.3. A 1.2 m (4 ft) or greater in width pathway and bordering 1.2 m (4 ft) by 2.5 m (8 ft) "venting cutouts" every 6.0 m (20 ft) on alternating sides of the pathway





Photo courtesy of DOE/NREL 214

UL **2012 IFC - PV Systems**


- **605.11.4 Ground-Mounted PV Arrays**
 - Ground-mounted PV arrays shall comply with Sections 605.11 through 605.11.2 and this section
 - Setback requirements shall not apply to ground-mounted, free-standing PV arrays
 - A clear, brush-free area of 3.0 m (10 ft) shall be required for ground-mounted PV arrays



Photos courtesy of DOE/NREL 215

UL **2012 IRC & IBC- PV Systems**

- **R905.16 & 1507.17 Photovoltaic Modules/Shingles**
The installation of PV modules/shingles shall comply with the provisions of this section
- **R905.16.1 & 1507.17.1 Material Standards**
Photovoltaic modules/shingles shall be listed and labeled in accordance with UL 1703




SHARP SOLAR MODULE NT-S5E1U


THE ELECTRICAL CHARACTERISTICS ARE WITHIN ± 10 PERCENT OF THE INDICATED VALUES OF I_{sc} , V_{oc} , AND P_{max} UNDER STANDARD TEST CONDITIONS (IRRADIANCE OF 1000W/m², AM1.5 SPECTRUM AND CELL TEMPERATURE OF 25°C)

MAXIMUM POWER	(P_{max})	185.0 W
OPEN-CIRCUIT VOLTAGE	(V_{oc})	44.9 V
SHORT-CIRCUIT CURRENT	(I_{sc})	5.75 A
MAXIMUM POWER VOLTAGE	(V_{mp})	36.2 V
MAXIMUM POWER CURRENT	(I_{mp})	5.11 A
MAXIMUM SYSTEM VOLTAGE		600 V
FUSE RATING		10 A
FIRE RATING	CLASS	C
FIELD WIRING	COVER ONLY 14 AWG MIN. INSULATED FOR 90°C MIN.	
SERIAL No.	034090273	

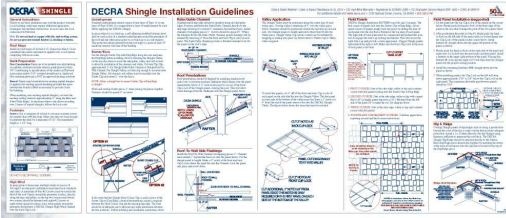
SHARP CORPORATION
385-1 HAKUWA, SHIRUO-CHO, KITAKATSURAGI-GU, NARA, 639-0198, JAPAN



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R905.16.2 & 1507.17.2 Attachment.
 PV modules/shingles **shall be attached** in accordance with the **manufacturer's installation instructions**.




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- **R905.16.3 & 1507.17.3 Wind Resistance**
 - PV modules/shingles **shall be tested in accordance** with procedures and acceptance criteria in ASTM D 3161.
 - PV modules/shingles **shall comply with the classification requirements** of Table R905.2.4.1(2) & Table 1507.2.7.1(2) for the appropriate **maximum basic wind speed**.
 - PV modules/shingle packaging **shall bear a label** to indicate compliance with the **procedures in ASTM D 3161** and the required classification from Table R905.2.4.1(2) & Table 1507.2.7.1(2).


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FOR FIELD CONNECTIONS;
 USE MINIMUM NO. 14 AWG (USE-2 or UL PV WIRE)
 COPPER WIRES INSULATED FOR MINIMUM OF 90° C.
 PREPARED ROOF COVERING MATERIALS DEGREE OF RESISTANCE TO
 EXTERNAL FIRE-CLASS A
 DEGREE OF WIND RESISTANCE INVESTIGATED IN ACCORDANCE WITH
 PROCEDURES ADOPTED FROM **ASTM D3161 AT A WIND SPEED OF 110 MPH**
 PREPARED ROOF COVERING MATERIALS FOR ROOFING SYSTEMS AS TO
 UPLIFT RESISTANCE
 ALSO CLASSIFIED BY UNDERWRITERS LABORATORIES INC. IN ACCORDANCE
 WITH IEC 61646

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- **M2302.2.1 Roof-Mounted Panels and Modules**
 - Where PV panels and modules are installed on roofs, the roof **shall be constructed to support the loads imposed** by such modules
 - Roof-mounted PV panels and modules that serve as roof covering shall conform to the requirements for roof coverings in Chapter 9
 - Where mounted on or above the roof coverings, the PV panels and modules and supporting structure **shall be constructed of noncombustible materials or fire-retardant-treated wood** equivalent to that required for the roof construction

[illegible]

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- M2302.3 Photovoltaic Panels and Modules**
Photovoltaic panels and modules **shall be listed and labeled** in accordance with UL 1703



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- **M2302.4 Inverters**
 - Inverters shall be listed and labeled in accordance with UL 1741
 - Systems connected to the utility grid shall use inverters listed for utility interaction

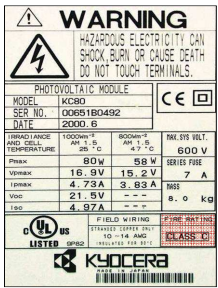


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- **1505.8 Photovoltaic Systems**
Rooftop installed photovoltaic systems that are adhered or attached to the roof covering or PV modules/shingles installed as roof coverings shall be labeled to identify their fire classification in accordance with the testing required in Section 1505.1



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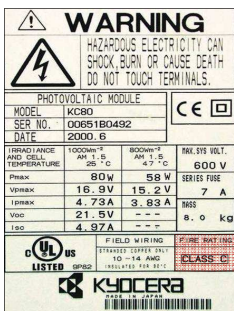
- **1509.7 Photovoltaic Systems**
Rooftop mounted PV systems shall be designed in accordance with this section
- **1509.7.1 Wind Resistance**
Rooftop mounted PV systems shall be designed for wind loads for component and cladding in accordance with Chapter 16 using an effective wind area based on the dimensions of a single unit frame

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- 1509.7.2 Fire Classification**
Rooftop mounted PV systems shall have the same fire classification as the roof assembly required by Section 1505



WARNING
HAZARDOUS ELECTRICITY CAN SHOCK, BURN OR CAUSE DEATH. DO NOT TOUCH TERMINALS.

PHOTOVOLTATIC MODULE

MODEL	KC80	CE	RECYCLED
SER. NO.	00651B0492		
DATE	2000. 6		

IRRADIANCE AND CELL TEMPERATURE	1000W/m ² AM 1.5, 25 °C	800W/m ² AM 1.5, 47 °C	MAX. SYS. VOLT.
Power	80 W	58 W	600 V
V _{PMAX}	16.9 V	15.2 V	SERIES FUSE
I _{PMAX}	4.73 A	3.83 A	7 A
V _{OC}	21.5 V	- - -	WGT
I _{SC}	4.97 A	- - -	8.0 kg

FIELD WIRING: STRAPPED CONNECT ONLY 10-14 AWG INSULATED FOR 90°C CLASS C


UL LISTED KYOCERA

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- 1509.7.3 Installation**
Rooftop mounted PV systems shall be installed in accordance with the manufacturer's installation instructions
- 1509.7.4 Photovoltaic Panels and Modules**
PV panels and modules mounted on top of a roof shall be listed and labeled in accordance with UL 1703 and shall be installed in accordance with the manufacturer's installation instructions



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- 1511.1 Solar photovoltaic Panels/Modules**
Solar PV panels/modules installed upon a roof or as an integral part of a roof assembly shall comply with the requirements of this code and the International Fire Code
- 1511.1.1 Structural Fire Resistance**
The structural frame and roof construction supporting the load imposed upon the roof by the PV panels/modules shall comply with the requirements of Table 601

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TABLE 601 FIRE-RESISTANCE RATING REQUIREMENTS FOR BUILDING ELEMENTS (HOURS)

BUILDING ELEMENT	TYPE I		TYPE II		TYPE III		TYPE IV		TYPE V	
	A	B	A*	B	A*	B	HT	A*	B	
Primary structural frame ^a (see Section 202)	3*	2*	1	0	1	0	HT	1	0	
Bearing walls										
Exterior ^a	3	2	1	0	2	2	2	1	0	
Interior	3*	2*	1	0	1	0	1/HT	1	0	
Nonbearing walls and partitions										
Exterior										
Interior ^a	0	0	0	0	0	0	See Section 602.4.6	0	0	
Floor construction and associated secondary member (see Section 202)	2	2	1	0	1	0	HT	1	0	
Roof construction and associated secondary members (see Section 202)	1 1/2	1*	1*	0*	1*	0	HT	1*	0	

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- **610.1 Renewable Energy Systems Requirements**
 - Buildings that consume energy shall comply with this section
 - Each building ... shall be equipped with one or more renewable energy systems in accordance with this section
 - Renewable energy systems shall comply with the requirements of Section 610.2 for solar photovoltaic systems, Section 610.3 for wind systems, or Section 610.4 for solar water heating systems, and Section 610.5 for performance monitoring and metering of these systems as approved by the Code Official
 - These systems shall be commissioned in accordance with the requirements of Section 611

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- **610.1.1 Building Performance-Based Compliance**

Buildings and surrounding property or building sites where there are multiple buildings on the building site...

 - that are designed and constructed in accordance with Section 601.3.1, Performance-Based Compliance...
 - shall be equipped with one or more renewable energy systems that have the capacity to provide not less than 2 percent of the total calculated annual energy use of the building, or collective buildings on the site



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- **610.1.2 Building Prescriptive Compliance**
Buildings that are designed and constructed in accordance with **Section 601.3.2, Prescriptive Compliance...**
 - shall be equipped with **one or more renewable energy systems** having the capacity to provide **not less than 2 percent** of the total estimated annual energy use of the building or collective buildings on the building site...
 - with onsite renewable energy demonstrating that onsite renewable energy production has a rating of not less than 1.75 Btu/h (0.5 W) or **not less than 0.50 watts per sq. ft. of conditioned floor area...**
 - and using any single or combination of renewable energy generation systems meeting the requirements of **Sections 610.2, 610.3, or 610.4**

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- **610.2 Solar Photovoltaic systems**
PV systems **shall be sized** to provide not less than 2 percent of the total estimated annual electric energy consumption of the building, or collective buildings on the building site in accordance with Section 610.1.1 or 610.1.2
- **610.2.1 Limitation**
PV systems **shall not be used** to comply with Section 610.1 where building sites have total global insolation levels lower than 2.00 kWh/m²/day as determined in accordance with NREL SERI TR-642-761

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- **610.2.2 Requirements**
The installation, inspection, maintenance, repair and replacement of PV systems and system components **shall comply with the manufacturer's instructions**, Section 610.2.2.1, the International Fire Code, the International Building Code and NFPA 70 (NEC)
- **610.2.2.1 Performance Verification**
 - PV systems **shall be tested on installation** to verify that the installed performance meets the design specifications
 - A report of the tested performance **shall be provided** to the building owner

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- **C402.2.1.1 Roof Solar Reflectance and Thermal Emittance**
 Low-sloped roofs, with a slope less than 2 units vertical in 12 horizontal, directly above cooled conditioned spaces in Climate Zones 1, 2, and 3 **shall comply with** one or more of the options in Table C402.2.1.1
 - **Exceptions:** The following roofs and portions of roofs are exempt from the requirements in Table C402.2.1.1:
 1. Portions of roofs that include or are covered by:
 - 1.1. Photovoltaic systems or components
 - 1.2. Solar air or water heating systems or components
 - 1.3. Roof gardens or landscaped roofs
 - 1.4. Above-roof decks or walkways
 - 1.5. Skylights
 - 1.6. HVAC systems, components, and other opaque objects mounted above the roof

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Solar Photovoltaic Systems



Thanks for Participating




Any Questions?

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